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RESEARCH MEMORANDUM

for the

Bureau of Aeronautics, Navy Department

WIND-TUNNEL TESTS OF A MODIFIED KOPPERS AEROMATIC IMPELLER-GENERATOR COMBINATION

TED NO. NACA ARR 2901

By

M. J. Queijo

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

An investigation was conducted in the 6- by 6-foot test section of the Langley stability tunnel on a modified Koppers Aeromatic wind-driven impeller-generator combination. This investigation consisted of a few fixed pitch tests and a series of variable pitch tests.

The fixed pitch tests indicated that the impeller should operate between the blade-pitch angles of 20° and 32° at the specified output of 11.7 kilowatts in order to remain within the specified rotational speeds of from 5000 to 8000 rpm for airspeeds of from 130 to 175 miles per hour.

The requirement that the impeller maintain rotational speeds of between 5000 and 8000 rpm as the impeller output varied from 0 to 11.7 kilowatts at airspeeds of from 130 to 175 miles per hour was not met at any time during the variable pitch tests. The main difficulty seemed to be the inability of the impeller blades to change blade-pitch angle smoothly and quickly as load conditions varied.

There was some indication that the vibration normally occuring on an airplane might cause the impeller to operate satisfactorily.

The best performance was obtained with a shield made of a piece of $1\frac{1}{2}$-inch angle iron, 17 inches long, placed about 1.8 inches upstream of the front end of the impeller and with the impeller variables set as follows: blade-phase angle -10°, counterweight

of 38 grams, counterweight angle of 34°, high-pitch stop set for 39°, low-pitch stop set for 20°, and with short 10.5° counterweight arms.

INTRODUCTION

At the request of the Bureau of Aeronautics, Navy Department, wind-tunnel tests were conducted on a Koppers Aeromatic wind-driven impeller-generator combination. This impeller is to be installed in utility-type aircraft and is to be used as a power unit with Navy type antiaircraft target reels.

The Navy specifies that the impeller maintain a rotational speed of between 5000 and 8000 rpm when its propelling airspeed varies between 130 and 175 miles per hour and the output varies between 0 and 11.7 kilowatts.

Tests, reported in reference 1, of an impeller equipped with steel blades showed that the impeller failed to meet the Navy requirements because of excessive rotational speeds under no-load conditions. The failure of the impeller to meet the Navy specifications was attributed to the inability of the blades to change pitch as load conditions varied. It was thought that the high bearing loads imposed by the centrifugal force of the steel impeller blades prevented the blades from changing pitch as the load conditions changed.

To reduce centrifugal force, the steel impeller blades were replaced by wooden blades. The tests reported herein were made with the wooden blades driving the generator. The tests were made to determine the characteristics of the modified impeller-generator combination in its present form and to furnish data to assist in the further development of the Koppers Aeromatic impeller.

A few fixed pitch tests were made to serve as a basis for determining the blade-pitch angle range for satisfactory operation of the impeller. All other tests were made with the impeller in variable pitch operation.

SYMBOLS

β blade-pitch angle, measured in a plane normal to the blade pivot axis and defined as the angle between the chord of the blade section (5 inches from the blade tip) and the plane of rotation

θ pivot angle, measured in a plane normal to the pivot axis and defined as the angle between the projection of the gravity axis of the blade and the plane of rotation

γ blade phase angle, measured in a plane normal to the pivot axis and defined as the angle between the chord of the blade and the projection of the gravity axis of the blade on this plane, positive when the blade is behind the plane of rotation

ϵ counterweight angle, measured in a vertical plane parallel to the axis of rotation of the blades and defined as the angle between the center line of the counterweight arm and the projection of the axis of rotation of the blades (when the blades are set against low-pitch stops)

ϕ flange construction angle, defined as the acute angle between the intersection of the pivot axis and the blade gravity axis, equals 6°

V_c calibrated airspeed, defined as the speed related to differential pressure by the accepted adiabatic formula used in the calibration of differential-pressure airspeed indicators and equal to true airspeed for standard sea-level conditions

APPARATUS AND METHODS

The tests of the impeller were conducted in the 6- by 6-foot test section of the Langley stability tunnel. A photograph of the impeller mounted in the tunnel is shown in figure 1. Details of the hub and blades are shown in figures 2 to 4. The impeller has a diameter of 26 inches and has laminated maple blades of Clark Y airfoil section. The operation of the impeller and the details of construction are described in detail in reference 1.

A schematic diagram of the electrical set-up is shown in figure 5. A variable resistance was placed in series with the generator shunt field. The strength of the field was varied by changing the variable resistance, and hence the power output of the generator was controlled. The power produced by the generator was fed into a group of resistors and was dissipated as heat. Power output was measured by means of a direct-current ammeter and a direct current voltmeter. (See fig. 6.) Impeller rotational speed was measured by an electrical (generator type) tachometer which was coupled to the rotor shaft of the generator.

The generator was cooled by means of an airscoop and duct which were fastened to the impeller base and which directed a stream of air into the generator housing.

For fixed-pitch tests, the counterweights were removed and the blade-pitch angle was set as follows: The flange was turned so that its axis was in the plane of rotation and the two pitch-stop screws were secured in this position. The counterweight arm was then loosened to permit rotation of the blade within the flange. The blade was set to the desired angle of pitch. The counterweight arm was clamped on the flange, thus preventing further rotation of the blade within the flange.

For variable pitch tests the impeller variables were set as follows: A calibrated counterweight was attached to each counterweight arm. The blade-pitch angle was set as for fixed-pitch tests. The range through which the flanges could turn (and thus change the blade-pitch angle) was established by selecting the length of stop screws which would allow the desired blade-pitch angle variation, and securing them in place. The counterweight arm was tightened just enough to keep the blades from rotating within the flanges. Finally, the counterweight angle was set as follows: The blade was rotated to the low-pitch position. The counterweight arm was turned until the counterweight clamp center line made the desired angle with the axis of rotation of the blade assembly. The counterweight arm was then clamped securely.

TESTS

The tests consisted of a few fixed-pitch tests for various values of blade-pitch angle at calibrated airspeeds from 100 to 200 miles per hour, and a series of variable-pitch tests in which the phase angle, counterweight angle, counterweight, and pitch-stop settings were varied.

Some variable-pitch tests were made with narrow shields placed upstream of the front end of the impeller. One of the shields is shown in figure 7.

In both the fixed-pitch and variable-pitch tests the power output was varied by changing the generator-field resistance while maintaining the airspeed constant. The airspeed is believed to be accurate to ±1 mile per hour.

All settings and data recordings were made by a representative of the Koppers Company. The instruments used were the property of the Koppers Company and were not calibrated at the Laboratory. All angle settings were made with a precision inclinometer. The impeller hub was statically balanced on the shaft and ways shown in figure 8. (The impeller shown is the impeller of reference 1.)

RESULTS AND DISCUSSION

Fixed-Pitch Tests

The results of the fixed-pitch tests are given in figure 9. Figure 9(a), which shows the variation of maximum generator output with blade-pitch angle for several airspeeds, indicates that if the impeller is to produce the output of 11.7 kilowatts, as specified by the Navy, the blade-pitch angle must vary from 20° at 130 miles per hour to not more than 32° at 175 miles per hour. Figure 9(b) shows that if the blade-pitch angles vary as indicated by figure 9(a), the rotational speed of the impeller will meet the Navy specifications.

Variable-Pitch Tests

The results of the variable-pitch tests of the impeller with no external shield are given in table I. Various combinations of phase angle, counterweight angle, and counterweight were tried with the impeller in Aeromatic operation. Three counterweight arms were tried. They were the old type used in the tests of reference 1 (arms referred to in this report as 8.5° arms), a new type (referred to as 10.5° arms), and the new type with approximately 0.5 inch cut from the end (short 10.5° counterweight arms). No combination was found which would meet the power and rotational speed requirements specified by the Navy. The impeller blades tended to reach one blade-pitch angle and remain there regardless of load. Several combinations were found where the blades would snap suddenly between high- and low-pitch stops as the load conditions varied. These tests seemed to indicate that there was excessive friction in the bearing and gear systems. In a few cases it was found that satisfactory operation could be obtained by tapping the impeller support. The vibration was evidently enough to shake the flanges and allow them to rotate freely. There is the possibility that in normal installations (impeller mounted on an airplane) the vibration of the airplane itself might be sufficient to cause the impeller to operate satisfactorily.

It was decided to try to find some alternate method of obtaining satisfactory operation in case the vibrations of the airplane installation were ineffective. The only feasible method seemed to be to reduce some of the forces on one of the blades at a time. This would leave the forces on the impeller unbalanced and then the blades would tend to turn. The centrifugal forces could not be reduced to any large extent. It was possible, however, to reduce the aerodynamic forces on one blade at a time by mounting a narrow shield from the tunnel wall in front of the impeller so that the shield extended almost to the impeller hub. As each blade came behind the shield it would be out of the high velocity region of the airstream and thus most of the aerodynamic load of the blades would be momentarily unbalanced.

The first shield used was a piece of $2\frac{1}{2}$-inch angle iron. (See fig. 7.) It was 17 inches long and was mounted on the tunnel wall about 3 inches upstream of the front end of the impeller. The shield extended to about 3 inches from the impeller hub axis. The impeller speed variation with load remained within the specified limits, but too much power was lost because of the shield. The power loss was reduced by cutting down the length of the shield from 17 to 12 inches, but impeller rotational speeds were not satisfactory.

The second shield used was a $\frac{3}{4}$-inch iron pipe which was 17 inches long and was mounted in two locations, (a) 3 inches upstream of the front end of the impeller and (b) 1 inch upstream of the front end of the impeller. For both locations the results obtained were the same as those obtained for the impeller with no shield. Output power loss was small, but the blades did not change pitch angle so as to give smooth operation. The trouble again seemed to be caused by excessive friction.

The preload screws in the flanges were loosened in an attempt to reduce the bearing friction. The attempt proved to be futile.

The $2\frac{1}{2}$-inch angle iron proved to be the better shield in making the impeller operate smoothly, therefore, it was decided to use a smaller angle iron ($1\frac{1}{2}$-inch angle iron, 17 inches long) in an attempt to obtain smooth operation with small power loss. Good results were obtained with the angle iron placed about 1.8 inches upstream of the impeller. The best results were obtained with a phase angle of -10°, the low-pitch stop set for a blade-pitch angle of 20°, the high-pitch stop set for a blade-pitch angle of 39°, a counterweight arm angle of 34°, a counterweight of 38 grams, and with short 10.5° counterweight arms. The results of tests made with this arrangement are plotted in figure 10 as curves of generator output against impeller speed for calibrated airspeeds of 100, 130, 150, and 175 miles per hour. Figure 10 shows that the impeller meets the power requirements, but operates under the specified lower limit of 5000 rpm at calibrated airspeeds of 130 and 150 miles per hour.

The impeller was found to be extremely sensitive to counterweight angle. At the settings given above, the impeller blades oscillated at airspeeds of about 30 to 50 miles per hour. A change of 1° (from 34° to 33°) caused the impeller to oscillate in the airspeed range of from about 100 to 150 miles per hour.

CONCLUDING REMARKS

The fixed-pitch tests indicate that the output requirement (11.7 kilowatts for a rotational speed range of from 5000 to 8000 rpm) can be met if the impeller blade-pitch angle varies from 20° at 130 miles per hour to 32° at 175 miles per hour.

The requirements of power output and rotational speed of the impeller were not met at any time during the variable-pitch tests. The main difficulty was that the impeller blades did not change pitch smoothly as load conditions were varied. This is believed to be caused by excessive friction in the bearing and gear systems. There was some indication that the vibration normally occuring on an airplane might cause the impeller to operate satisfactorily.

The use of a shield to provide unsteady aerodynamic forces on the impeller gave good regulation in some cases, but the power output or impeller rotational speeds did not remain within the limits specified by the Navy.

The best performance was obtained with a shield made of a piece of $1\frac{1}{2}$-inch angle iron, 17 inches long, and placed about 1.8 inches upstream of the front end of the impeller and with the impeller variables set as follows: blade-phase angle -10°, counterweight of 38 grams, counterweight angle of 34°, high-pitch stop set for 39°, low-pitch stop set for 20°, and with short 10.5° counterweight arms.

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MEL

REFERENCE

1. Levitt, Joseph, and Morewitz, Bernard A.: Wind-Tunnel Tests of the Koppers Aeromatic Impeller-Generator Combination. NACA MR No. L5G17, Bur. Ordnance, Navy Dept., 1945.

TABLE I(a).- SUMMARY OF RESULTS OF TESTS ON A KOPPERS AEROMATIC IMPELLER IN VARIABLE PITCH OPERATION

Blade phase angle 15° 10.5° counterweight arms			Construction angle leads rotation			
			Stops			
Calibrated airspeed (mph)	Impeller speed (rpm)	Generator output watts	High pitch (deg)	Low pitch (deg)	Counter-weight grams	Counter-weight angle (deg)
100	4200	6105	41	15	0	24
100	5000	6105	41	15	0	24
100	6200	4950	41	15	0	24
100	7200	2200	41	15	0	24
100	7900	20	41	15	0	24
130	6000	14280	41	15	0	24
100	2200	975	41	15	27.5	24
100	2500	0	41	15	27.5	24
130	2800	2200	41	15	27.5	24
130	3200	0	41	15	27.5	24
150	3300	3240	41	15	27.5	24
150	3700	0	41	15	27.5	24
100	2100	585	41	15	13.9	24
130	2800	2090	41	15	13.9	24
130	3200	0	41	15	13.9	24
100	4200	6290	41	15	0	24
130	2800	2200	41	15	3.9	24
130	3200	0	41	15	3.9	24
150	3300	3375	41	15	3.9	24
150	3700	0	41	15	3.9	24

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TABLE I(b)[a].- SUMMARY OF RESULTS OF TESTS ON A KOPPERS

AEROMATIC IMPELLER IN VARIABLE PITCH OPERATION

Blade phase angle 25° 10.5° counterweight arms			Construction angle leads rotation			
Calibrated airspeed (mph)	Impeller speed (rpm)	Generator output watts	Stops High pitch (deg)	Stops Low pitch (deg)	Counter-weight grams	Counter-weight angle (deg)
100	4100	5940	47	15	0	20
100	5000	5940	47	15	0	20
100	5800	5100	47	15	0	20
100	7200	2090	47	15	0	20
100	8000	30	47	15	0	20
100	4200	5940	47	15	13.5	20
100	4900	5940	47	15	13.5	20
100	5800	5270	47	15	13.5	20
100	7000	2415	47	15	13.5	20
100	7800	45	47	15	13.5	20
100	4200	6105	33.5	15	13.5	20
100	7800	20	33.5	15	13.5	20
100	2800	1995	33.5	15	27	20
100	3400	0	33.5	15	27	20
130	3600	4480	33.5	15	27	20
130	4400	0	33.5	15	27	20
150	4200	6460	33.5	15	27	20
150	5100	5	33.5	15	27	20
100	4200	6105	33.5	15	16	20
100	7800	45	33.5	15	16	20
100	4200	6105	33.5	15	20.5	20
100	7500	20	33.5	15	20.5	20
130	3600	4340	33.5	15	20.5	20

[a]New flange bearings were installed at the start of these tests.

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TABLE I(b).- SUMMARY OF RESULTS OF TESTS ON A KOPPERS AEROMATIC

IMPELLER IN VARIABLE PITCH OPERATION - Concluded

Blade phase angle 25° 10.5° counterweight arms			Construction angle leads rotation			
Calibrated airspeed (mph)	Impeller speed (rpm)	Generator output watts	Stops: High pitch (deg)	Stops: Low pitch (deg)	Counter-weight grams	Counter-weight angle (deg)
130	4500	5	33.5	15	20.5	20
100	2700	1995	33.5	15	23	20
100	3400	0	33.5	15	23	20
100	2700	1995	33.5	15	21.8	20
130	3600	4340	33.5	15	21.8	20
130	2400	0	33.5	15	21.8	20
150	4200	6460	33.5	15	21.8	20
150	5100	5	33.5	15	21.8	20
100	2700	1995	33.5	15	20.5	20
130	3500	4200	33.5	15	3.8	25
130	4300	0	33.5	15	3.8	25
100	4000	6105	33.5	15	0	25
100	7600	0	33.5	15	0	25
100	4000	6105	33.5	15	(b)	25
100	7200	45	33.5	15	(b)	25
100	4000	5940	33.5	15	(c)	25
100	7100	45	33.5	15	(c)	25
100	2700	1890	33.5	15	0	28
100	3300	0	33.5	15	0	28

[b]Values obtained with 3.8 grams counterweight on blades 1 and 3, no counterweight on blades 2 and 4.

[c]Values obtained with 4.9 grams counterweight on blades 1 and 3, no counterweight on blades 2 and 4.

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TABLE I(c).- SUMMARY OF RESULTS OF TESTS ON A KOPPERS

AEROMATIC IMPELLER IN VARIABLE PITCH OPERATION

Blade phase angle 25° 8.5° counterweight arms			Construction angle leads rotation			
Calibrated airspeed (mph)	Impeller speed (rpm)	Generator output watts	Stops: High pitch (deg)	Stops: Low pitch (deg)	Counter-weight grams	Counter-weight angle (deg)
100	4000	6105	33.5	15	0	44.5
100	7900	20	33.5	15	0	44.5
100	3000	2875	33.5	15	42	44.5
100	3900	0	33.5	15	42	44.5
130	4000	5940	33.5	15	42	44.5
130	5100	0	33.5	15	42	44.5
130	5300	11250	33.5	15	28	44.5
130	7700	45	33.5	15	28	44.5
130	4600	7980	33.5	15	35	44.5
130	6200	20	33.5	15	35	44.5
130	4000	5760	33.5	15	42	41.5
130	4900	5	33.5	15	42	41.5
130	4600	8580	33.5	15	35	41.5
130	6300	20	33.5	15	35	41.5

TABLE I(d).- SUMMARY OF RESULTS OF TESTS ON A KOPPERS

AEROMATIC IMPELLER IN VARIABLE PITCH OPERATION

Blade phase angle 15° 8.5° counterweight arms			Construction angle leads rotation			
Calibrated airspeed (mph)	Impeller speed (rpm)	Generator output watts	Stops: High pitch (deg)	Stops: Low pitch (deg)	Counter-weight grams	Counter-weight angle (deg)
130	5800	13720	37	15	35	41.5
130	8700	60	37	15	35	41.5
130	4800	9430	37	15	42	41.5
130	6600	20	37	15	42	41.5

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TABLE I(e).- SUMMARY OF RESULTS OF TESTS ON A KOPPERS

AEROMATIC IMPELLER IN VARIABLE PITCH OPERATION

Blade phase angle 15° 10.5° counterweight arms			Construction angle leads rotation				
Calibrated airspeed (mph)	Impeller speed (rpm)	Generator output watts	Stops High pitch (deg)	Stops Low pitch (deg)	Counter-weight grams	Counter-weight angle (deg)
130	4400	7200	37	15	0	30
130	5400	5	37	15	0	30
130	4600	8170	37	15	0	25
130	6100	5	37	15	0	25
130	5800	14000	37	15	0	20
130	3100	2875	37	15	14	20
130	3600	0	37	15	14	20
130	5800	13750	37	15	3.8	20
130	4800	9000	37	15	6	20
130	6500	20	37	15	6	20
130	5900	13750	37	15	6	20

TABLE I(f).- SUMMARY OF RESULTS OF TESTS ON A KOPPERS

AEROMATIC IMPELLER IN VARIABLE PITCH OPERATION

Blade phase angle -10° 10.5° counterweight arms			Construction angle leads rotation			
Calibrated airspeed (mph)	Impeller speed (rpm)	Generator output watts	Stops High pitch (deg)	Stops Low pitch (deg)	Counter-weight grams	Counter-weight angle (deg)
130	5900	14250	34	15	6	20
130	6000	14250	34	15	8	20
130	3400	3370	34	15	41	20
130	4000	5	34	15	41	20

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TABLE I(g).- SUMMARY OF RESULTS OF TESTS ON A KOPPERS

AEROMATIC IMPELLER IN VARIABLE PITCH OPERATION

Blade phase angle -10° Short 10.5° counterweight arms			Construction angle leads rotation			
Calibrated airspeed (mph)	Impeller speed (rpm)	Generator output watts	Stops High pitch (deg)	Stops Low pitch (deg)	Counter-weight grams	Counter-weight angle (deg)
100	4000	6105	34	15	0	35
100	7500	20	34	15	0	35
100	4000	6105	34	15	14	35
100	7500	20	34	15	14	35
100	3100	2990	34	15	42	35
100	3800	0	34	15	42	35
100	4000	5760	34	15	28	35
100	6200	5	34	15	28	35
100	3500	4340	34	15	35	35
100	4800	0	34	15	35	35
130	5000	9870	34	15	35	35
130	6400	20	34	15	35	35
150	5800	12720	34	15	35	35
150	7400	80	34	15	35	35
125	4600	10500	34	15	35	35
125	5200	9675	34	15	35	35
100	3000	2875	34	15	42	30
100	3800	0	34	15	42	30
100	3400	3500	34	15	42	30
100	3900	0	34	15	42	30
130	4000	5940	34	15	42	30
130	5100	5	34	15	42	30
150	4900	8800	34	15	42	30
150	5900	20	34	15	42	30
100	4000	5600	34	15	42	30
130	5400	11250	34	15	42	30
130	3800	5	34	15	42	30
130	3800	4800	34	15	42	30
130	4600	5	34	15	42	30

At the settings listed on this page for airspeeds of 100 miles per hour the impeller blades changed from high to low pitch as the load varied, however, the change was not smooth and the impeller rotational speed was higher than desired.

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TABLE I(g).- SUMMARY OF RESULTS OF TESTS ON A KOPPERS AEROMATIC

IMPELLER IN VARIABLE PITCH OPERATION - Continued

Blade phase angle -10° Short 10.5° counterweight arms			Construction angle leads rotation			
Calibrated airspeed (mph)	Impeller speed (rpm)	Generator output watts	Stops High pitch (deg)	Stops Low pitch (deg)	Counter-weight grams	Counter-weight angle (deg)
100	3800	5100	34	15	42	32
100	3300	0	34	15	42	32
130	4500	7200	34	15	42	32
130	5500	20	34	15	42	32
100	4000	5940	34	15	35	32
100	5500	20	34	15	35	32
100	4000	5760	34	15	38	32
100	3600	0	34	15	38	32
130	5600	12220	34	15	38	32
130	6500	45	34	15	38	32
130	5600	12588	34	15	35	32
130	7400	80	34	15	35	32
100	4000	5940	34	15	35	32
100	4600	20	34	15	35	32
100	3400	4050	34	15	35	32
100	3500	4050	39	20	35	32
100	2600	0	39	20	35	32
130	5000	9660	39	20	35	32
130	3400	5	39	20	35	32
100	3700	4800	39	20	35	32
100	4000	4200	39	20	35	32
100	4200	1615	39	20	35	32
100	4400	45	39	20	35	32
100	3200	0	39	20	35	32
[d]100	3600	4495	39	20	35	32
120	4600	7790	39	20	35	32
120	3600	5	39	20	35	32
130	5000	9450	39	20	35	32
130	5600	20	39	20	35	32
130	4400	11200	39	20	38	33
130	3700	10	39	20	38	33

[d]A new synchronizer gear was installed.

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TABLE I(g).- SUMMARY OF RESULTS OF TESTS ON A KOPPERS AEROMATIC

IMPELLER IN VARIABLE PITCH OPERATION - Continued

Blade phase angle -10° Short 10.5° counterweight arms			Construction angle leads rotation			
Calibrated airspeed (mph)	Impeller speed (rpm)	Generator output watts	Stops: High pitch (deg)	Stops: Low pitch (deg)	Counter-weight grams	Counter-weight angle (deg)
150	5400	16380	39	20	38	33
150	4200	40	39	20	38	33
175	6200	22500	39	20	38	33
175	7000	15200	39	20	38	33
175	4900	40	39	20	38	33
175	7300	90	39	20	38	33
130	4400	11200	39	20	38	33
130	5000	8400	39	20	38	33
130	5300	3600	39	20	38	33
130	5100	40	39	20	38	33
[e]100	3000	4830	39	20	38	33
100	3800	10	39	20	38	33
130	4300	10850	39	20	38	33
130	3700	10	39	20	38	33
150	5200	16770	39	20	38	33
150	4100	10	39	20	38	33
175	6500	25440	39	20	38	33
175	7300	160	39	20	38	33
130	4800	8800	39	20	38	33
130	5200	10	39	20	38	33
100	3000	4600	39	20	38	33
100	3900	3600	39	20	38	33
100	3800	560	39	20	38	33
100	3100	10	39	20	38	33
130	4400	11200	39	20	38	33
130	5300	7830	39	20	38	33
130	5300	2880	39	20	38	33
130	3600	10	39	20	38	33
150	5200	16770	39	20	38	33

[e]At this point in the tests the preload screws of the flanges were loosened and remained loose for the remainder of the variable pitch tests.

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TABLE I(g).- SUMMARY OF RESULTS OF TESTS ON A KOPPERS AEROMATIC

IMPELLER IN VARIABLE PITCH OPERATION - Concluded

Blade phase angle -10° Short 10.5° counterweight arms			Construction angle leads rotation			
Calibrated airspeed (mph)	Impeller speed (rpm)	Generator output watts	Stops High pitch (deg)	 Low pitch (deg)	Counter-weight grams	Counter-weight angle (deg)
150	6200	9900	39	20	38	33
150	6100	3230	39	20	38	33
150	6200	90	39	20	38	33
175	6400	26400	39	20	38	33
175	7000	19740	39	20	38	33
175	7400	12580	39	20	38	33
175	7700	250	39	20	38	33
130	5000	8800	39	20	38	33

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TABLE II(a).- SUMMARY OF RESULTS OF TESTS ON A KOPPERS AEROMATIC IMPELLER IN VARIABLE PITCH OPERATION WITH VARIOUS THIN SHIELDS

Blade phase angle -10° Short 10.5° counterweight arms Shield: 2.5-inch angle iron, 17 inches long, and 3 inches upstream of impeller			Construction angle leads rotation			
Calibrated airspeed (mph)	Impeller speed (rpm)	Generator output watts	Stops: High pitch (deg)	Stops: Low pitch (deg)	Counter-weight grams	Counter-weight angle (deg)
100	3400	4050	39	20	0	32
100	4000	5760	34	15	0	40
100	7400	20	34	15	0	40
100	4000	5760	34	15	14	40
100	7400	20	34	15	14	40
100	4000	5760	34	15	28	40
100	5200	0	34	15	28	40
100	3900	5425	34	15	30.9	40
100	4500	1615	34	15	30.9	40
100	4700	0	34	15	30.9	40
130	5400	11960	34	15	30.9	40
130	5800	6825	34	15	30.9	40
130	6400	45	34	15	30.9	40
150	6300	16200	34	15	30.9	40
150	7400	125	34	15	30.9	40
100	3900	5425	34	15	30.9	36
100	4600	0	34	15	30.9	36
130	5400	11250	34	15	30.9	36
130	6300	45	34	15	30.9	36
150	6400	15370	34	15	30.9	36
150	7200	125	34	15	30.9	36
100	3700	4495	34	15	35	36
100	4000	0	34	15	35	36
130	4900	8800	34	15	35	36
130	5500	20	34	15	35	36

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TABLE II(a).- SUMMARY OF RESULTS OF TESTS ON A KOPPERS

AEROMATIC IMPELLER IN VARIABLE PITCH OPERATION

WITH VARIOUS THIN SHIELDS- Concluded

Blade phase angle -10° Short 10.5° counterweight arms Shield: 2.5-inch angle iron, 17 inches long, and 3 inches upstream of impeller			Construction angle leads rotation			
Calibrated airspeed (mph)	Impeller speed (rpm)	Generator output watts	Stops		Counter-weight grams	Counter-weight angle (deg)
			High pitch (deg)	Low pitch (deg)		
150	5800	12720	34	15	35	36
150	6300	45	34	15	35	36
100	3700	4785	34	15	35	34
100	4000	0	34	15	35	34
130	4800	9225	34	15	35	34
130	5400	5	34	15	35	34
150	5800	13230	34	15	35	34
150	6200	20	34	15	35	34
170	6600	16800	34	15	35	34
170	7200	80	34	15	35	34
180	6800	17400	34	15	35	34
180	7600	125	34	15	35	34
100	3700	4640	36.5	17.5	35	34
100	3700	0	36.5	17.5	35	34
130	4800	8385	36.5	17.5	35	34
130	4800	5	36.5	17.5	35	34
150	5500	11730	36.5	17.5	35	36
150	5700	20	36.5	17.5	35	36
170	6100	14820	36.5	17.5	35	36
170	6400	45	36.5	17.5	35	36

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TABLE II(b) .- SUMMARY OF RESULTS OF TESTS ON A KOPPERS AEROMATIC IMPELLER IN VARIABLE PITCH OPERATION WITH VARIOUS THIN SHIELDS

Blade phase angle -10° Short 10.5° counterweight arms Shield: 3/4-inch iron pipe, 17 inches long, and 3 inches upstream of impeller			Construction angle leads rotation			
Calibrated airspeed (mph)	Impeller speed (rpm)	Generator output watts	Stops High pitch (deg)	Stops Low pitch (deg)	Counter-weight grams	Counter-weight angle (deg)
100	3800	5100	36.5	17.5	35	34
100	4400	0	36.5	17.5	35	34
100	3200	5250	36.5	17.5	35	34
130	4500	12540	36.5	17.5	35	34
130	5600	40	36.5	17.5	35	34
150	5500	18400	36.5	17.5	35	34
150	6500	120	36.5	17.5	35	34
175	5900	22880	36.5	17.5	35	34
175	7800	250	36.5	17.5	35	34
100	3300	5280	36.5	17.5	35	34
100	4400	40	36.5	17.5	35	34
130	4600	11880	36.5	17.5	35	34
130	5700	2550	36.5	17.5	35	34
130	6000	90	36.5	17.5	35	34
150	5100	15580	36.5	17.5	35	34
150	6900	160	36.5	17.5	35	34
175	6000	22050	36.5	17.5	35	34
175	7900	250	36.5	17.5	35	34
130	4600	12210	36.5	17.5	35	34
130	5000	11880	36.5	17.5	35	34
100	3000	4800	39	20	35	34
100	4000	10	39	20	35	34
130	4400	10850	39	20	35	34
130	5600	90	39	20	35	34
150	5200	15960	39	20	35	34
150	6500	120	39	20	35	34

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TABLE II(b).- SUMMARY OF RESULTS OF TESTS ON A KOPPERS

AEROMATIC IMPELLER IN VARIABLE PITCH OPERATION

WITH VARIOUS THIN SHIELDS - Continued

Blade phase angle -10° Short 10.5° counterweight arms Shield: 3/4-inch iron pipe, 17 inches long, and 3 inches upstream of impeller			Construction angle leads rotation			
Calibrated airspeed (mph)	Impeller speed (rpm)	Generator output watts	Stops High pitch (deg)	Stops Low pitch (deg)	Counter-weight grams	Counter-weight angle (deg)
175	5800	20640	39	20	35	34
175	7600	250	39	20	35	34
100	3000	4600	39	20	38	34
100	3700	10	39	20	38	34
130	4400	10850	39	20	38	34
130	4800	5980	39	20	38	34
130	4900	40	39	20	38	34
150	5000	14800	39	20	38	34
150	5700	1320	39	20	38	34
150	5800	90	39	20	38	34
175	5600	18860	39	20	38	34
175	6600	3060	39	20	38	34
175	6800	160	39	20	38	34
100	3000	4600	39	20	38	32
100	2900	0	39	20	38	32
130	4400	11520	39	20	38	32
130	3800	10	39	20	38	32
150	5300	17160	39	20	38	32
150	5400	90	39	20	38	32
175	6300	24440	39	20	38	32
175	5000	40	39	20	38	32
100	3000	4600	39	20	38	33
100	3600	3230	39	20	38	33
100	3400	0	39	20	38	33
130	4400	10850	39	20	38	33
130	4900	8100	39	20	38	33
130	3700	10	39	20	38	33

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TABLE II(b).- SUMMARY OF RESULTS OF TESTS ON A KOPPERS AEROMATIC IMPELLER IN VARIABLE PITCH OPERATION WITH VARIOUS THIN SHIELDS - Concluded

Blade phase angle -10° Short 10.5° counterweight arms Shield: 3/4-inch iron pipe, 17 inches long, and 3 inches upstream of impeller			Construction angle leads rotation			
			Stops			
Calibrated airspeed (mph)	Impeller speed (rpm)	Generator output watts	High pitch (deg)	Low pitch (deg)	Counter-weight grams	Counter-weight angle (deg)
150	5300	16770	39	20	38	33
150	5800	7540	39	20	38	33
150	4200	40	39	20	38	33
175	5900	20210	39	20	38	33
175	6700	14800	39	20	38	33
175	6600	160	39	20	38	33
100	3000	4830	39	20	38	33

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TABLE II(c).- SUMMARY OF RESULTS OF TESTS ON A KOPPERS

AEROMATIC IMPELLER IN VARIABLE PITCH OPERATION

WITH VARIOUS THIN SHIELDS

Blade phase angle -10° Short 10.5° counterweight arms Shield: 3/4-inch iron pipe, 17 inches long, and 1 inch upstream of impeller			Construction angle leads rotation			
Calibrated airspeed (mph)	Impeller speed (rpm)	Generator output watts	Stops: High pitch (deg)	Stops: Low pitch (deg)	Counter-weight grams	Counter-weight angle (deg)
100	3000	4600	39	20	38	33
100	3700	10	39	20	38	33
130	4400	10850	39	20	38	33
130	4800	40	39	20	38	33
150	4900	14000	39	20	38	33
150	5600	90	39	20	38	33
175	5600	18860	39	20	38	33
175	6600	160	39	20	38	33
[f]100	2900	4600	39	20	38	33
100	3100	0	39	20	38	33
130	4200	11160	39	20	38	33
130	3800	10	39	20	38	33
150	5000	18060	39	20	38	33
150	4600	40	39	20	38	33
175	6000	22000	39	20	38	33
175	5000	40	39	20	38	33
182	6300	23000	39	20	38	33
182	6300	90	39	20	38	33

[f]The flange preload screws were loosened at this point and remained loose for the rest of the variable pitch tests.

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TABLE II(d).- SUMMARY OF RESULTS OF TESTS ON A KOPPERS AEROMATIC IMPELLER IN VARIABLE PITCH OPERATION WITH VARIOUS THIN SHIELDS

Blade phase angle -10° Short 10.5° counterweight arms Shield: 1.5-inch angle iron, 17 inches long, and 1.8 inches upstream of impeller			Construction angle leads rotation			
Calibrated airspeed (mph)	Impeller speed (rpm)	Generator output watts	Stops: High pitch (deg)	Stops: Low pitch (deg)	Counter-weight grams	Counter-weight angle (deg)
100	3000	4600	39	20	38	33
100	3200	1200	39	20	38	33
100	3200	0	39	20	38	33
130	4200	10850	39	20	38	33
130	4400	5980	39	20	38	33
130	4200	10	39	20	38	33
150	5100	16770	39	20	38	33
150	5200	9280	39	20	38	33
150	4900	40	39	20	38	33
175	6100	22500	39	20	38	33
175	5600	8990	39	20	38	33
175	5800	90	39	20	38	33
130	4300	10850	39	20	38	33
130	4600	8680	39	20	38	33
130	4200	3600	39	20	38	33
130	4300	40	39	20	38	33
150	5100	15960	39	20	38	33
150	5100	7280	39	20	38	33
130	4300	10850	39	20	38	34
130	4200	4830	39	20	38	34
130	4100	1680	39	20	38	34
130	4100	10	39	20	38	34
150	5100	17220	39	20	38	34
150	5000	8100	39	20	38	34
150	5000	3060	39	20	38	34
150	4800	40	39	20	38	34

The impeller oscillated in the airspeed range of from 100 to 150 miles per hour for the settings listed on this page for a counterweight angle of 33°.

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TABLE II(d).- SUMMARY OF RESULTS OF TESTS ON A KOPPERS AEROMATIC IMPELLER IN VARIABLE PITCH OPERATION WITH VARIOUS THIN SHIELDS - Concluded

Blade phase angle -10° Short 10.5° counterweight arms Shield: 1.5-inch angle iron, 17 inches long, and 1.8 inches upstream of impeller			Construction angle leads rotation			
Calibrated airspeed (mph)	Impeller speed (rpm)	Generator output watts	Stops: High pitch (deg)	Stops: Low pitch (deg)	Counter-weight grams	Counter-weight angle (deg)
175	6000	22500	39	20	38	34
175	6000	13300	39	20	38	34
175	5800	4400	39	20	38	34
175	5800	90	39	20	38	34
193	6300	90	39	20	38	34
100	3000	4600	39	20	38	34
100	3400	3600	39	20	38	34
100	3000	4600	39	20	35	34
100	3800	3400	39	20	35	34
100	3400	900	39	20	35	34
100	3400	0	39	20	35	34
100	3000	4600	39	20	38	34
100	3300	2100	39	20	38	34
100	3200	250	39	20	38	34
100	3200	0	39	20	38	34
130	4200	10200	39	20	38	34
130	4200	5750	39	20	38	34
130	4200	900	39	20	38	34
130	4200	5	39	20	38	34
150	5000	15170	39	20	38	34
150	5000	8400	39	20	38	34
150	4900	2400	39	20	38	34
150	4900	40	39	20	38	34
175	5800	21120	39	20	38	34
175	5800	9600	39	20	38	34
175	5800	4400	39	20	38	34
175	5800	45	39	20	38	34

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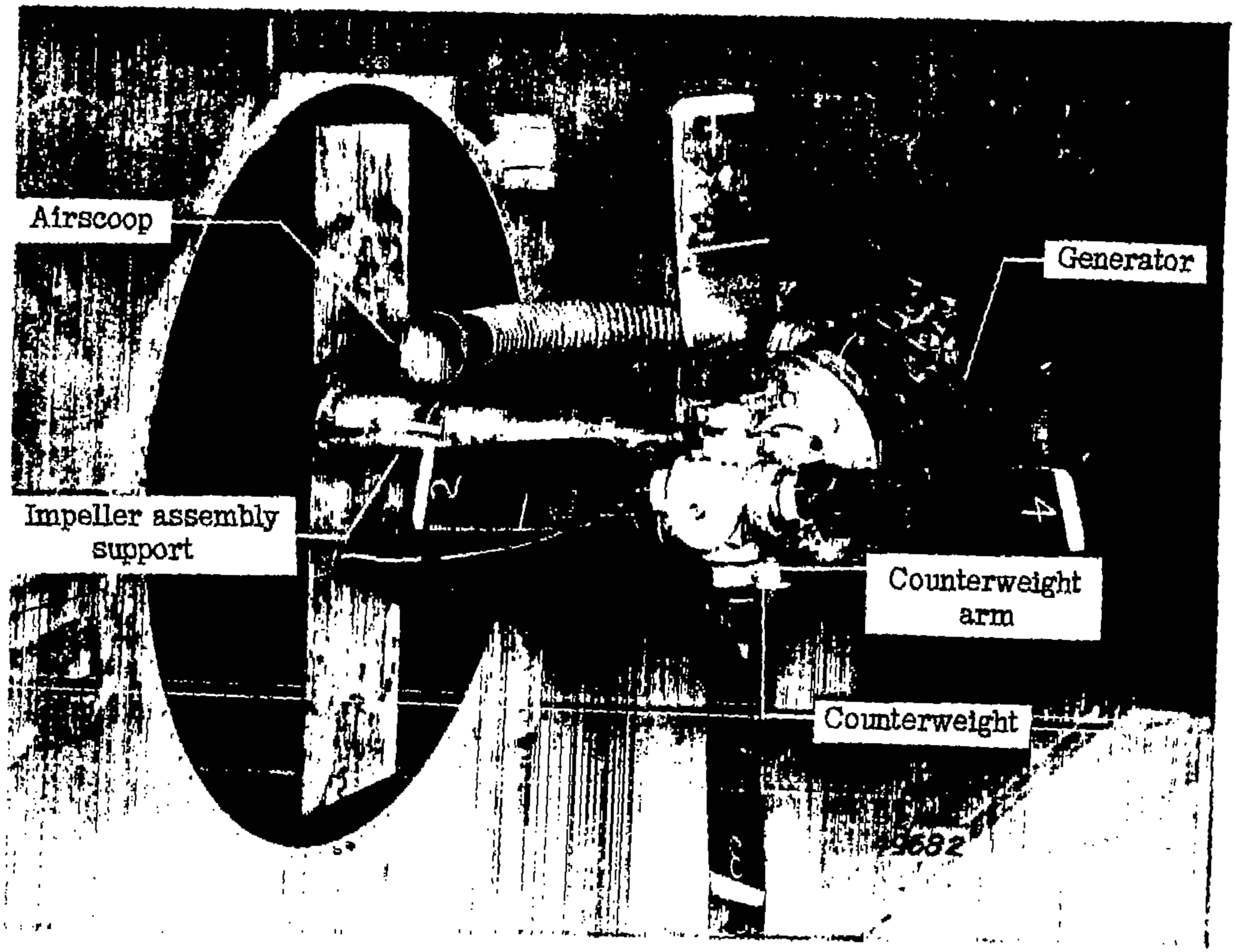

Figure 1.- View of Kopper's Aeromatic impeller-generator combination.

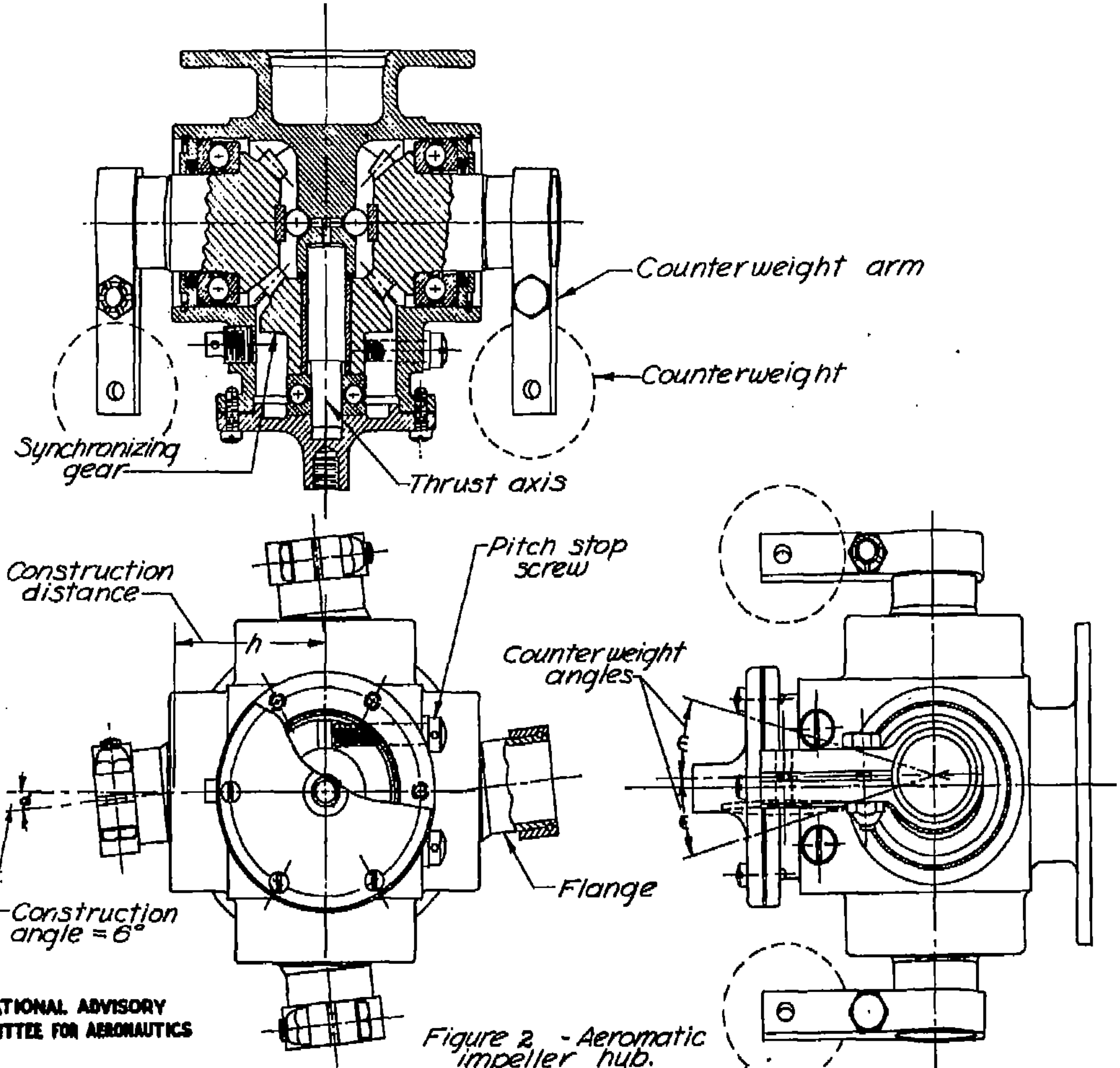

Figure 2 - Aeromatic impeller hub.

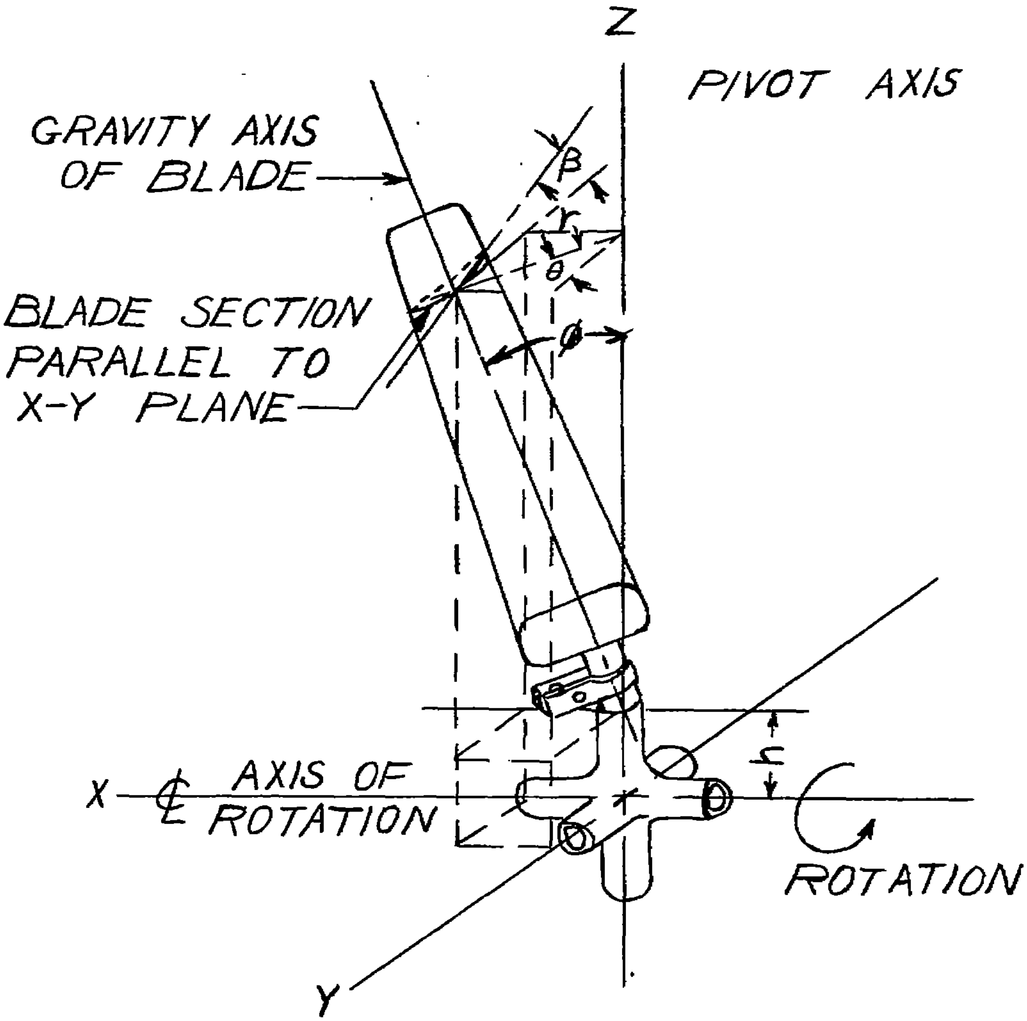

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Figure 3.- Schematic geometrical arrangement of blade with hub.

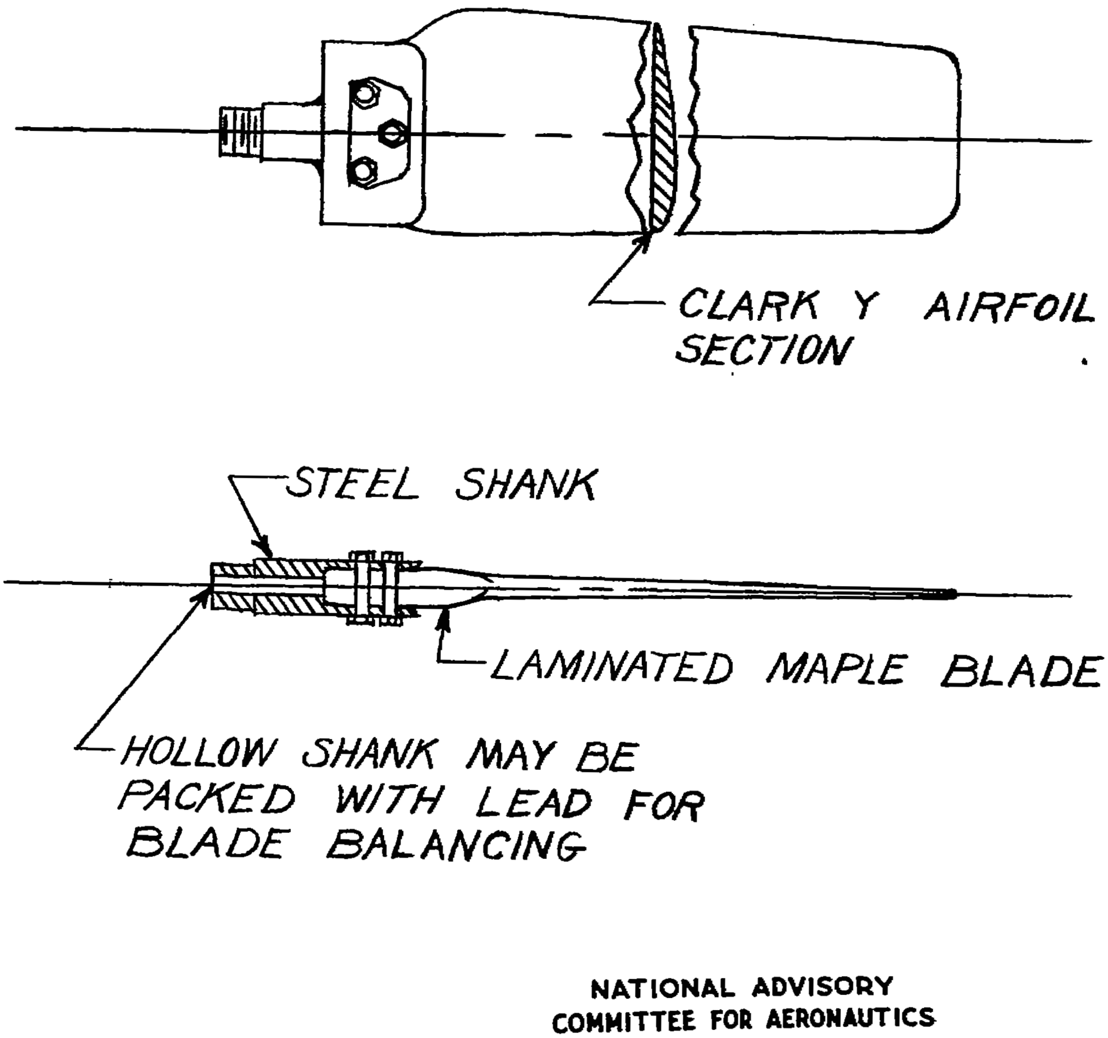

Figure 4.- Modified blade and shank of the Koppers Aeromatic Impeller.

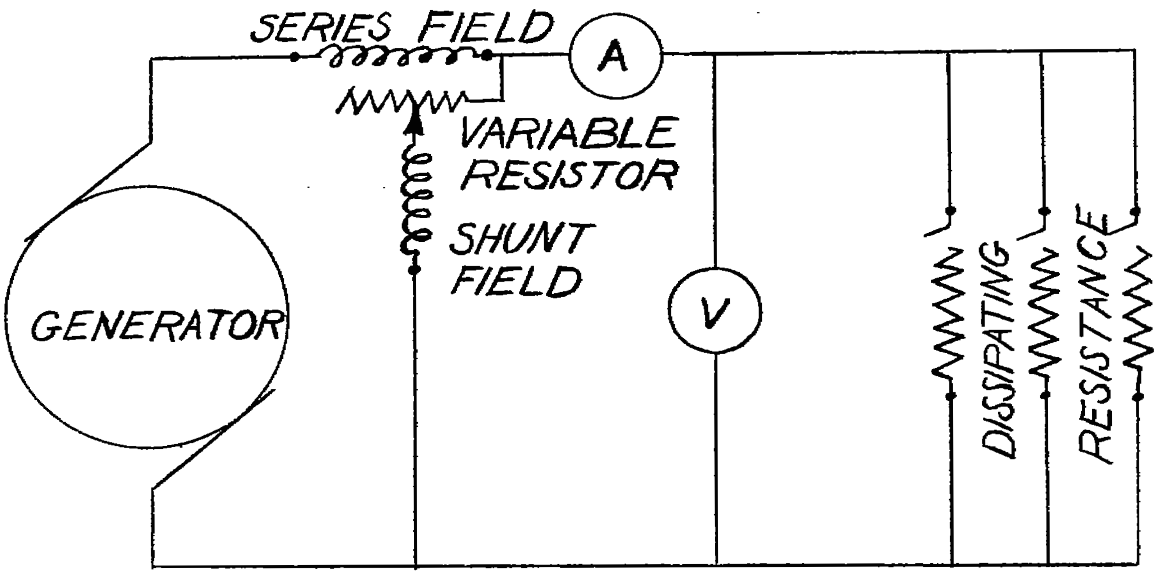

Figure 5.- Schematic diagram of generator and resistance circuit.

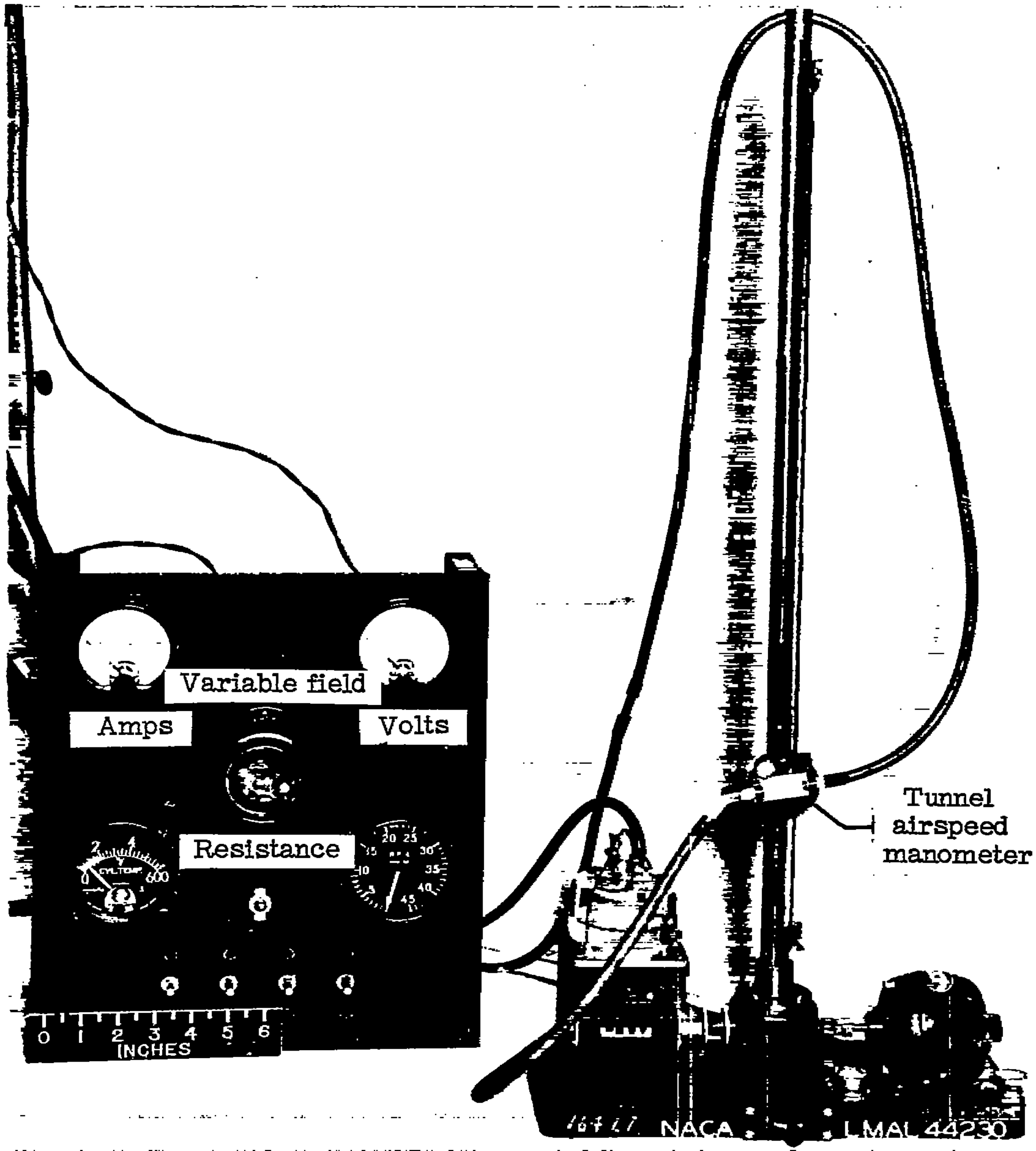

Figure 6.- Instrument panel for Kopper's Aeromatic impeller-generator combination.

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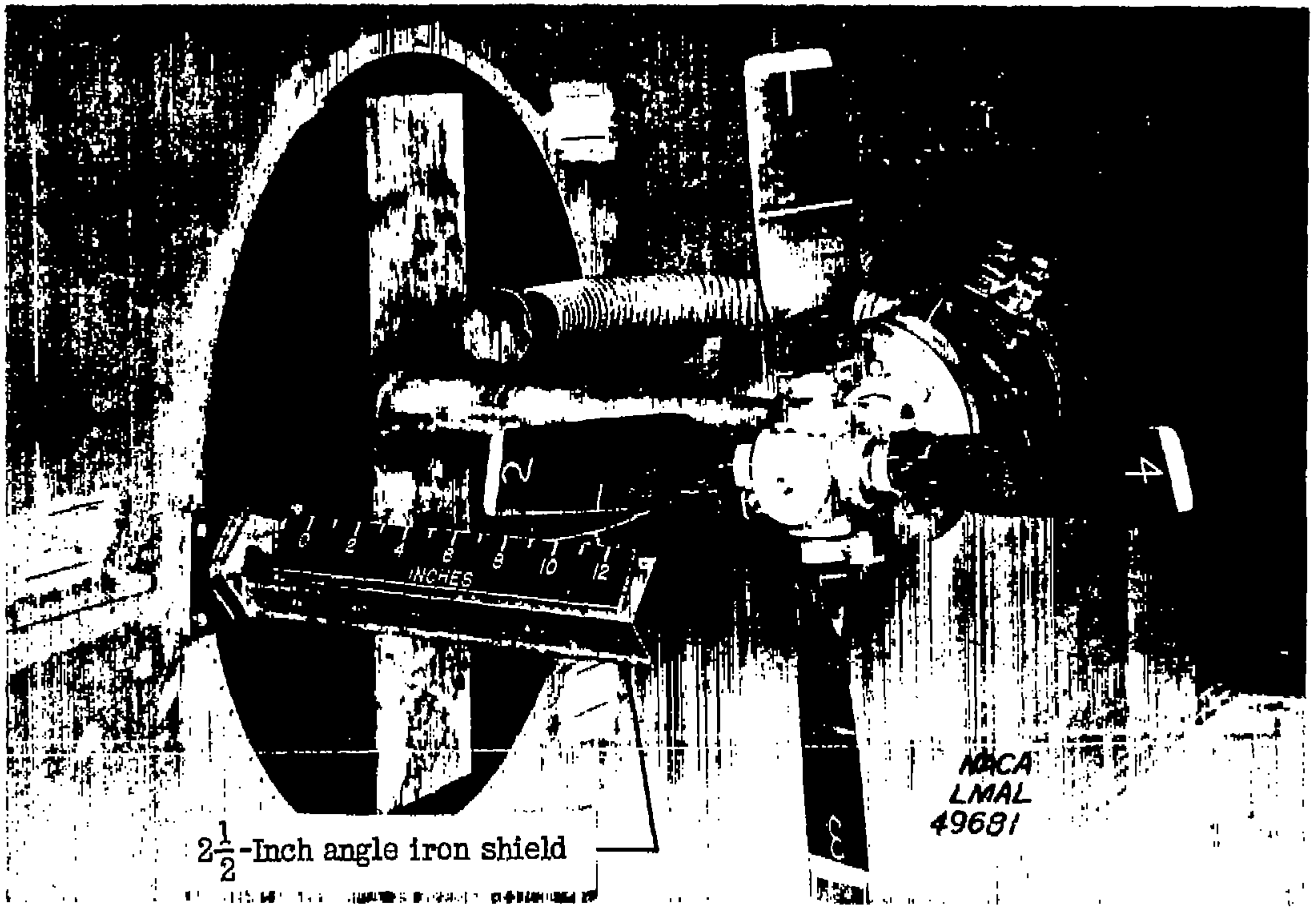

Figure 7.- View of Kopper's Aeromatic impeller-generator combination with a $2\frac{1}{2}$-inch shield.

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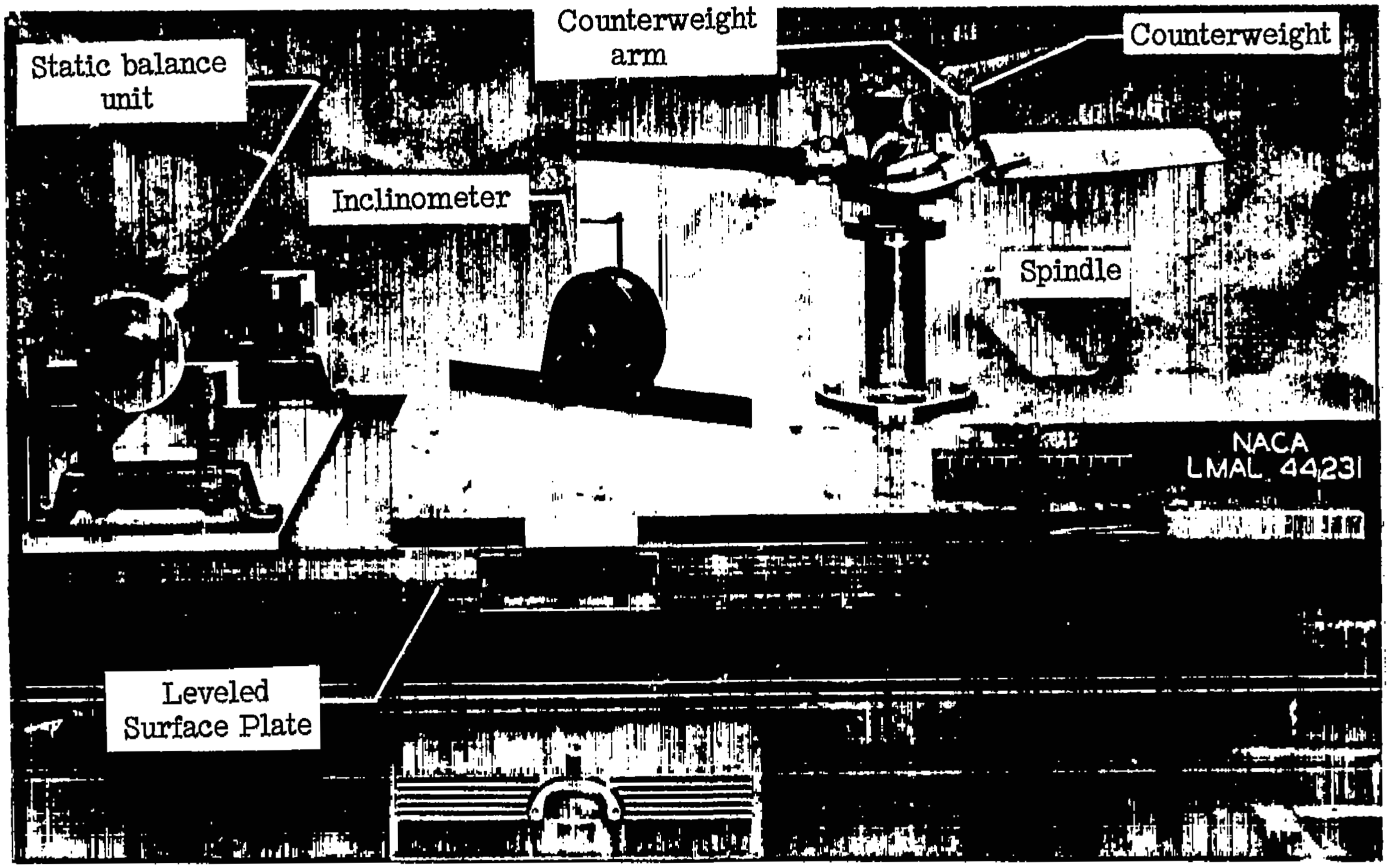

Figure 8.- Static balancing unit and angle setting jig with Kopper's Aeromatic impeller.

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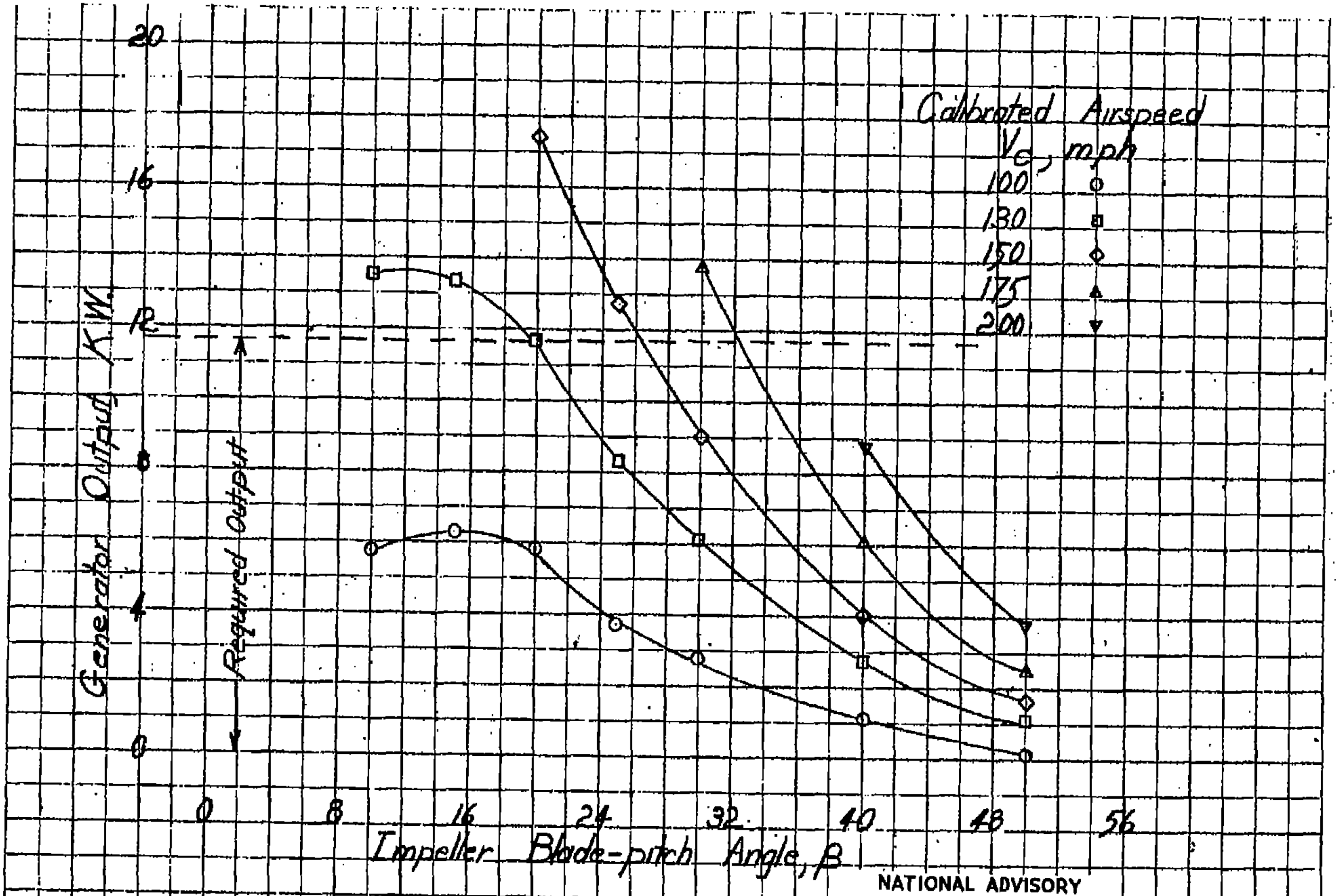
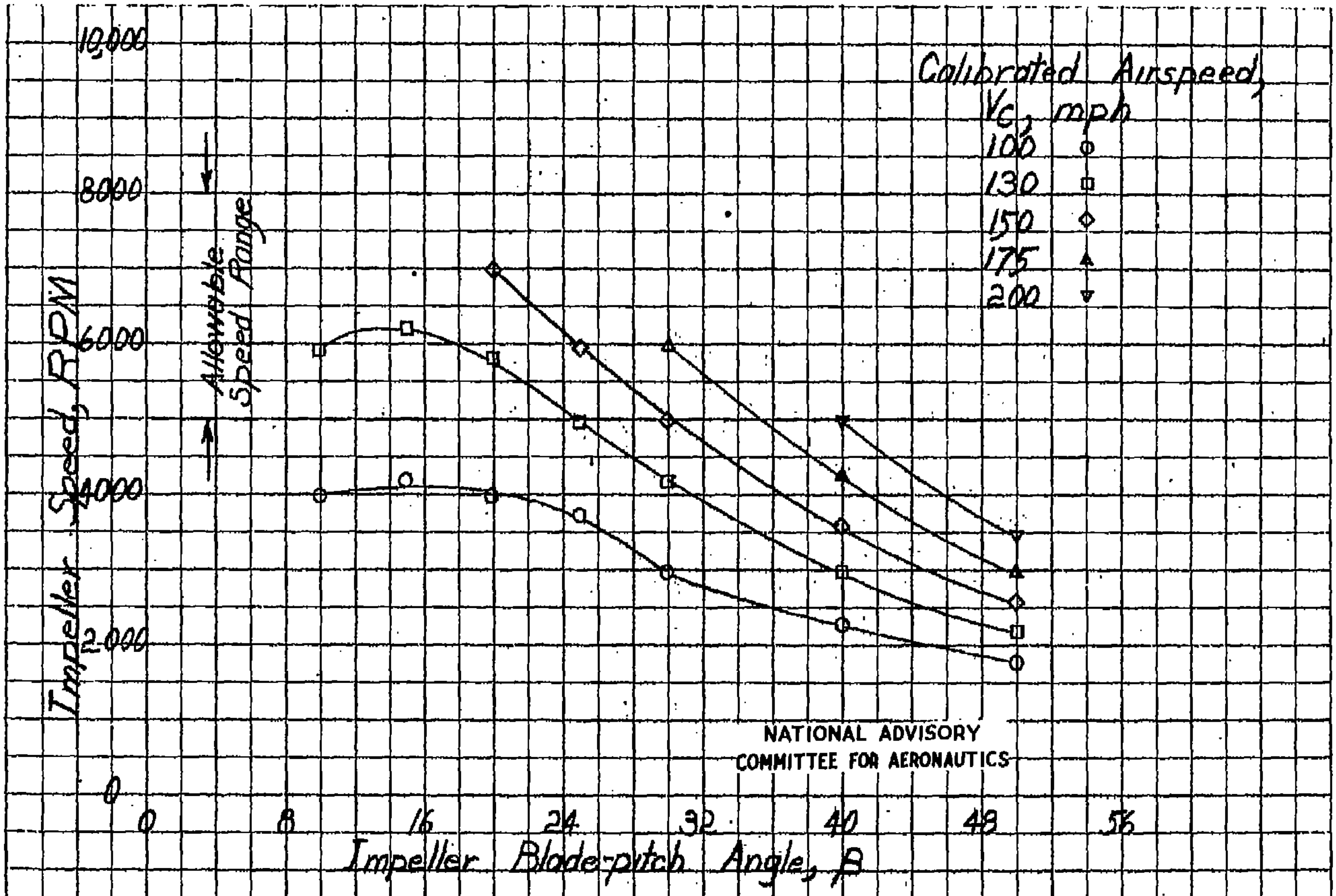


(a) Variation of maximum generator output with blade-pitch angle.

Figure 9.- Fixed pitch characteristics of the Koppers Aerovatic impeller-generator combination with modified blades.



(b) Variation of impeller speed with blade-pitch angle for maximum output conditions

Figure 9.- Concluded

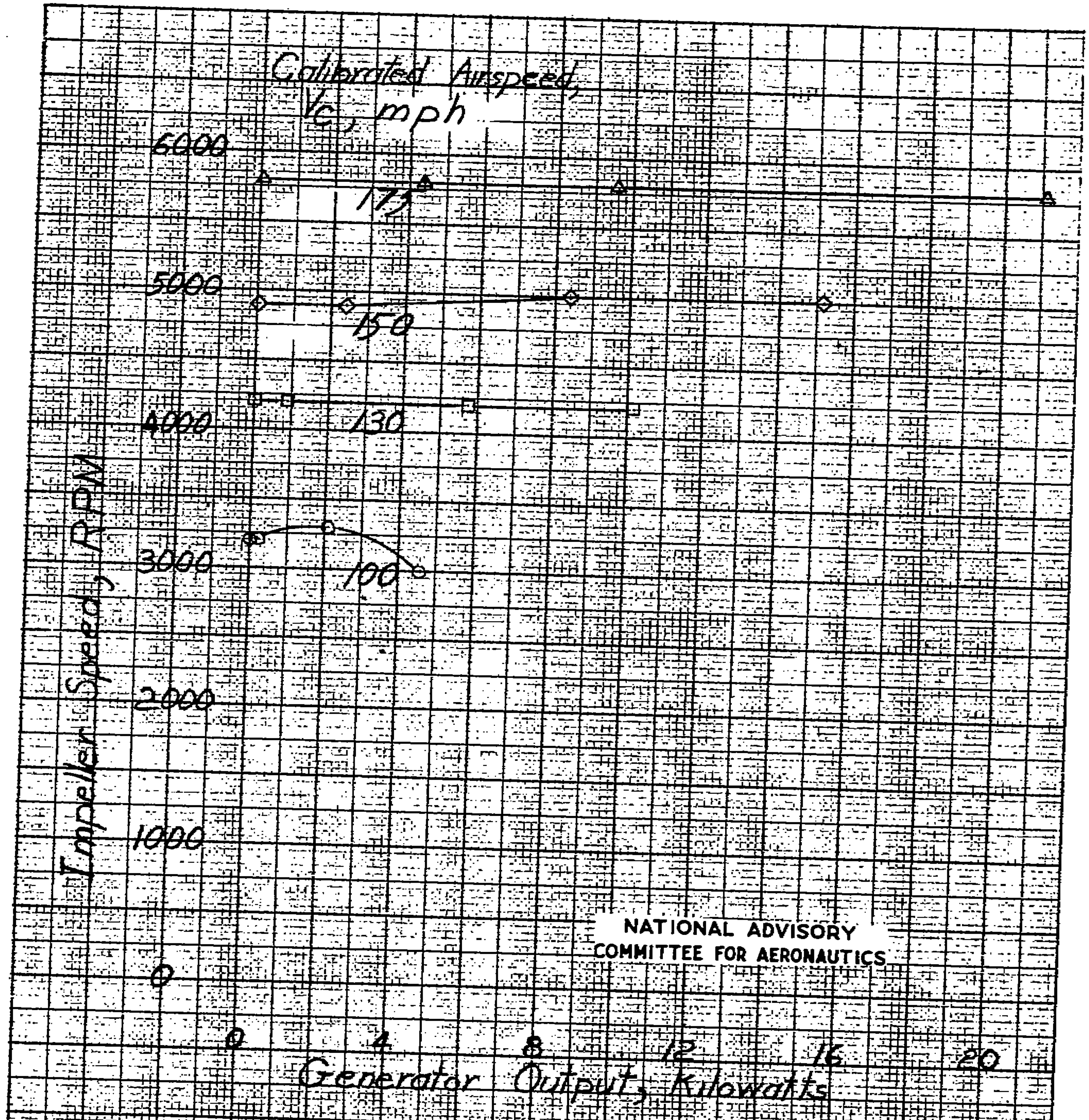


Figure 10.- Characteristics of the Koppers Aeromatic impeller-generator combination in aeromatic operation with a 1-1/2-inch angle shield 17 inches long placed 1-3/4 inches upstream of the impeller. Phase angle -30°, low blade-pitch stop 20°, high blade-pitch stop 39°, counterweight angle 34°, counterweight 38 grams, short 10.5° counterweight arms.